



MyTeachingPartner-Math/Science pre-kindergarten curricula and teacher supports: Associations with children's mathematics and science learning[☆]

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ABSTRACT

MyTeachingPartner-Math/Science (MTP-MS) is a system of two curricula (math and science) plus teacher supports designed to improve the quality of instructional interactions in pre-kindergarten classrooms and to scaffold children's development in mathematics and science. The program includes year-long curricula in these domains, and a teacher support system (web-based supports and in-person workshops) designed to foster high-quality curricular implementation. This study examined the impacts of the intervention on the development of mathematics and science skills of 444 children during pre-kindergarten, via school-level random assignment to two intervention conditions (*Basic*: MTP-M/S mathematics and science curricula, and *Plus*: MTP-M/S mathematics and science curricula plus related teacher support system) and a Business-As-Usual control condition (*BaU*). There were intervention effects for children's knowledge and skills in geometry and measurement as well as number sense and place value: Children in *Plus* classrooms made greater gains in geometry and measurement, compared with those in *BaU* classrooms. Children in *Plus* classrooms also performed better on the number sense and place value assessment than did those in *Basic* or *BaU* classrooms. We describe the implications of these results for supporting the development of children's knowledge and skills in early childhood and for developing and providing teachers with professional development to support these outcomes.

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Introduction

Early childhood experiences help develop the foundational mathematics and science skills that allow children to fully engage in creative problem solving, collaboration, and learning (National

Association for the Education of Young Children [NAEYC] & National Council of Teachers of Mathematics [NCTM], 2002; National Research Council [NRC], 2006). In fact, early play and experiences that engage children with the real world can lead to significant informal mathematical and scientific understandings (Clements, 2004a; Duschl, Schweingruber, & Shouse, 2007), and help develop the capacity for complex and abstract thought (Bowman, Donovan, & Burns, 2001). This informal knowledge provides the basis for the development of formal knowledge and skills across curricular domains, and particularly in mathematics and science (Bowman et al., 2001). Children's early mathematics and science knowledge and skills predict later school achievement (Claessens & Engel, 2013; Grissmer, Grimm, Aiyer, Murrah, & Steele, 2010; National Mathematics Advisory Panel [NMAP], 2008) and are a more significant predictor of later academic success than are early reading skills (Duncan et al., 2007).

This potential is often not achieved, however, as opportunities for learning are missed in the early childhood classroom with important mathematics and science concepts and skills covered in cursory ways (Balfanz, 1999), or as discrete topics without broad

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linkages and applications (NAEYC & NCTM, 2002; NRC, 2005). Little instructional time is spent on mathematics and science activities. For example, results from the National Center for Early Development and Learning's (NCEDL) national studies (Early et al., 2010) showed that children were exposed to mathematics activities during only 8% of classroom time, and to science activities for only 11% of classroom time, compared to 17% of classroom time in Language and Literacy activities and most of the time observed spent in "no coded learning activity" (44%).

Children from families with lower levels of education and income are at greatest risk for insufficient mathematics and science instruction; child care and early education programs which these children typically attend have been observed to be "of such low quality that learning and development are not enhanced and may even be jeopardized" (Bowman et al., 2001, p. 8). Children from disadvantaged backgrounds demonstrate fewer key mathematical skills at school entry: Results from analyses using the Early Childhood Longitudinal Study – Birth Cohort (ECLS-B) suggest that only 45% of four-year-olds from very poor families are proficient with numbers and shapes, compared to 72% of peers from families at or above the poverty level (NCES, 2009). These children's educational experiences do not serve to close this gap; instead the gap has been observed to widen. Upon Kindergarten entry, children from families with two or more risk factors have shown a seven-point gap in mathematics performance compared to their more advantaged peers; this gap has been seen to widen to 15 points by the conclusion of the third grade (NCES, 2011). Although high-quality learning experiences that build knowledge and skills are critical for all preschoolers, they are even more important for children from disadvantaged backgrounds (NMAP, 2008).

High-quality curricula have been found to support children's mathematics and science learning (Clements & Sarama, 2008; French, 2004; Starkey, Klein, & Wakeley, 2004). However, large-scale studies suggest that even when pre-k teachers are provided with validated curricula, they frequently struggle to implement them with quality and fidelity, likely due to teachers' lack of subject-area content knowledge and confidence (Pianta et al., 2005). This is a problem of particular importance in mathematics and science, where early childhood educators are not well-prepared, receive little professional development (NRC, 2006), and are less confident and less experienced than in other content areas (Copley, 2004; Stipek, 2008). Embedding professional development support within curricular materials can help encourage transfer of desired teaching practices to the classroom. Delivering this professional development support via the Internet can increase scalability and accessibility (NRC, 2007), and therefore may be more likely to make a detectable difference in the practice of a large number of teachers.

In this manuscript, we report the results of a year-long study designed to test the effects of the early childhood mathematics and science curricula, *MyTeachingPartner–Math/Science* (MTP-M/S), and an accompanying teacher support system on children's early mathematics and science learning in a sample of preschool children who are at-risk for negative school outcomes. To begin, we provide an overview of the previous research in this area and present the research-based model that supports the design of the MTP-M/S curricula and teacher supports. Then, we present our findings and discuss implications for the design and implementation of mathematics and science curricula and companion teacher support system aimed at improving children's mathematics and science knowledge and skills.

Informal development of early mathematics and science skills

Over the past few decades, research has shown that, prior to any formal schooling, young children from ages 0 to 5 develop

early informal everyday mathematics skills that are surprisingly broad and complex (Ginsburg, Lee, & Boyd, 2008) and at times, sophisticated (Zur & Gelman, 2004). This informal development typically includes ideas involving basic number sense and operations (Baroody, Lai, & Mix, 2006; Bryant, 1995; Clements & Sarama, 2007a), counting (Baroody, 1992; Frye, Braisby, Lowe, Maroudas, & Nicholls, 1989; Gelman & Gallistel, 1978; Stock, Desoete, & Roeyers, 2009; Wynn, 1990) and geometric thinking (e.g., size, shape, location, and patterns; see Clements, 2004b; Clements, Swaminathan, Hannibal, & Sarama, 1999). Young children also begin to develop basic problem solving and an understating of simple calculation concepts (Levine, Jordan, & Huttenlocher, 1992). This informal mathematics development is not only a natural progression, but a fundamentally important life skill. As Ginsburg, Lee, et al. (2008) suggest, "everyday mathematics is so fundamental and pervasive a feature of the child's cognition that it is hard to see how children could function without it" (p. 3).

Research also indicates that young children can understand scientific concepts such as the life cycle, growth and change, and distinctions between animate and inanimate objects (Bakscheider, Shatz, & Gelman, 1993; Inagaki & Hatano, 1996; Springer & Keil, 1991). Moreover, preschool age children are capable of reasoning scientifically. For instance, they are able to infer how misleading evidence can lead to forming a false belief (Ruffman, Olson, Ash, & Keen, 1993). More recent research has suggested that by the age of six, children can differentiate between hypotheses and evidence (Ruffman, Perner, Olson, & Doherty, 1993; Sodian, Zaitchik, & Carey, 1991), which is earlier than prior research had suggested (Kuhn, 1989; Piaget & Inhelder, 1969). Thus, young children are not only capable of engaging in mathematics and science thinking and learning, but they also possess substantial informal understandings that can serve as the basis for formal mathematics and science knowledge and skills.

MyTeachingPartner–Math and Science curricula and teacher support system

MyTeachingPartner–Math/Science (MTP-M/S) curricula were designed in response to the need for high-quality pre-k mathematics and science curricula. Their design was responsive to the foci above, informed by the research in early mathematics (Clements, 2004a; Ginsburg, Lee, et al., 2008; Klivanoff, Levine, Huttenlocher, Vasilyeva, & Hedges, 2006; Sarama & Clements, 2003) and science education (Duschl et al., 2007; French, 2004; Gelman & Brennenman, 2004; National Research Council [NRC], 2006), and in alignment with national and state standards. The curricula possess similar activity designs and forms of teacher supports and also reference concepts reflective of both mathematics and science wherever possible, but were designed to also stand alone. Each curriculum includes two activities (each activity 15–20 min in length) every week, for 33 weeks across the school year. Weekly "center time" options enable the teacher to revisit specific mathematics and science activities with small numbers of purposefully selected students. Table 1 provides an overview of the curricular activity design, the activity domains and sub-domains addressed, and the numbers of activities corresponding to each.

Table 1 also describes the MTP-M/S Teacher Support System to encourage teachers' curricular implementation fidelity – both their adherence to the curricula as designed and the quality of their related interactions with students in the classroom – as well as support the development of teachers' pedagogical and content knowledge. Some of these supports are embedded in the curricula and provided to all teachers (the "within activity supports" are part of the MTP-M/S Basic curricular package), and many others are separately delivered as part of MTP-M/S Plus (curricula plus

Table 1
MyTeachingPartner-Mathematics/Science curricula and professional development intervention.

For each curriculum (the <i>MTP-M/S Basic</i> curricular package):			
<ul style="list-style-type: none"> • 66 activities presented in explicit four-step inquiry format, each 15–20 min in length, in either whole or small-group format. Two activities are completed each week, for 33 weeks across the school year • “Within Activity” curricular supports (provided to <i>all</i> teachers using the curricula): <ul style="list-style-type: none"> - Identification of language to model and elicit - Recommendations for teachers’ questioning during the inquiry process - Adaptations to enable differentiated instruction for students needing more support or more challenge - A range of suggested extension activities • Weekly Centers: Choice of either mathematics- or science-related center activity • Mathematics- and Science-related books (18 for mathematics and 28 for science) and activity manipulatives 			
Standards addressed	Curricular domains	Number of activities ^a	<i>MTP-M/S Plus</i> teacher support system
MyTeachingPartner-Mathematics Designed to address: <ul style="list-style-type: none"> • National Council of Teachers of Mathematics (NCTM) Focal Areas for Pre-K (2006) • Clements (2004) Developmental trajectories for grades P-2 	<ul style="list-style-type: none"> • Number <ul style="list-style-type: none"> - Oral counting - Object counting - Numeral recognition (incl. foundational place value) • Operations <ul style="list-style-type: none"> - Equal partitioning - Combining/separating • Geometry <ul style="list-style-type: none"> - Shapes - Patterns • Measurement <ul style="list-style-type: none"> - Length - Weight - Area/volume 	38 (57.6%) 16 (24.2%) 28 (42.4%) 22 (33.3%) 11 (16.7%) 7 (10.6%) 5 (7.6%) 10 (15.2%) 8 (12.1%) 3 (4.6%) 13 (19.7%) 6 (9.1%) 3 (4.6%) 4 (6.1%)	Online-only teaching supports provided include: <ul style="list-style-type: none"> • Supports for every activity: <ul style="list-style-type: none"> - 2–3 min video demonstration - Brief teaching tip emphasizing one of the following: <ul style="list-style-type: none"> ○ Best teaching practice ○ Concept knowledge ○ How children learn • Weekly 5 min challenge ($n = 33$): <ul style="list-style-type: none"> - Reflective prompt on teaching practice, to be answered while watching a provided videotape of one of the week’s activities. Feedback on the practice issue provided by an expert in mathematics or science education • Quality teaching dimension of the month: <ul style="list-style-type: none"> - 1–2 min video demonstrates excellent practice on one of 10 dimensions of quality - Brief description of how that dimension matters - Links to library of over 150 video examples
MyTeachingPartner-Science State Standards used to refine focus for Pre-K, based on: <ul style="list-style-type: none"> • K-2 Standards Benchmarks from the American Association for the Advancement of Science (AAAS) (1993) • K-4 National Science Education Standards (National Research Council, 2006) 	<ul style="list-style-type: none"> • Life science <ul style="list-style-type: none"> - Humans - Animals - Plants • Earth science <ul style="list-style-type: none"> - Weather - Day/night - Earth materials • Physical science <ul style="list-style-type: none"> - Properties of materials - Movement - Physical change 	36 (54.5%) 20 (30.3%) 20 (30.3%) 13 (19.7%) 16 (24.2%) 7 (10.6%) 5 (7.8%) 7 (10.6%) 20 (30.3%) 17 (25.8%) 9 (13.6%) 10 (15.2%)	Professional devel. workshops: <ul style="list-style-type: none"> • 1 full-day, 7 half-day (2.5 h) workshops <ul style="list-style-type: none"> - Intro to/review of quality teaching (2) - Mathematics and quality teaching (2) - Science and quality teaching (4)

^a Number and percentage out of the total of 66 mathematics or 66 science activities. Single activities frequently addressed more than one topical area within a domain, and occasionally more than one curricular domain.

a teacher support system), which will be described later in this paper.

MTP-M/S curricular design

The activity designs for both mathematics and science reflect a focus on a careful scaffolding for knowledge and skill development across the year. As recommended by [Justice and Pullen \(2003\)](#), we attempted to balance meaningful student-centered interactions on topics that are relevant to children and teacher-guided, intentional teaching that ensures exposure to key skills and concepts. The activity design draws upon instructional theories related to structured inquiry, situated cognition anchored in authentic investigation, and cognitive development. Structured inquiry can be thought of as mid-way on an inquiry continuum that ranges from completely teacher-directed to totally student-driven ([Rezba, Auldridge, & Rhea, 1999](#); as cited in [Bell, Smetana, & Binns, 2005](#)). In structured inquiry, teachers ensure exposure to key constructs by posing questions, suggesting procedures, and guiding students learning. At the same time, students are purposively invited to inquire: the teacher’s interesting questions engage their attentions as they work with the teacher and their peers to investigate (manipulating materials whenever possible) and observe related phenomena. The process concludes with students analyzing and discussing their observations, then extending and applying what they learned, a modification of the 5E Model ([Bybee et al., 2006](#)).

Situating cognition, by anchoring instructional activities within the authentic experience of the everyday world, and the problems found within it, is thought to afford the development of richer understandings due to learners’ more active engagement – their *situated* cognition – while addressing the problems they tackle ([Brown, Collins, & Duguid, 1989](#); [Cognition and Technology Group at Vanderbilt \[CTGV\], 1990](#)). In the context of *MTP-M/S* activities, students follow life cycles of plants, animals, and themselves across the year, both within and outside of their classroom. They make predictions and follow with observations and experimentation to answer questions about the natural and man-made worlds. For example, students come to understand what the plants around them need in order to thrive, by conducting an experiment: With seedlings they have planted, they make predictions and observe what will occur when they provide light and water, light but no water, water but no light, and neither light nor water.

To develop mathematical understandings and skills, children count and measure themselves and their belongings, share numbers of toys and snacks fairly, and recognize geometries in the world around them. These undertakings frequently begin with an authentic everyday problem, such as how to share cookies fairly with friends, for which relevant mathematics understandings (in this case, equal partitioning and combining/separating) are recalled, further developed, and applied, as when students share six cookies in different ways, to provide for two children, three children, or six children.

To help scaffold for both student and teacher conceptual understandings, inquiries are often launched through use of children's literature (18 books in mathematics and 28 in science). Through reading and discussion, the teacher and students develop a solid foundation from which to launch an inquiry, as in the case of an interactive reading of *Bugs Are Insects* (Rockwell, 2001), followed by students' use of hand lenses for close examination of insects brought into the classroom and observed on nature walks. Book use preceding science inquiry has been found to be effective in the primary grades (Hapgood, Magnusson, & Palincsar, 2004).

As part of our iterative curricular development/evaluation process, we discovered the importance of scaffolding teachers' open-ended questioning and explicit language-development activities, to stimulate students' cognitive development. The importance of young children being able to think and talk about what they can do in both mathematics and science has been identified by leading researchers in the field (Gelman & Brenneman, 2004; Ginsburg, Lee, et al., 2008), as has the relationship between teachers' mathematical talk and students' mathematical development (Klibanoff et al., 2006). We incorporated many open-ended questions for teachers' use, along with mathematics and science language to both model for and elicit from students.

MTP-Math

We drew upon the National Council of Teachers of Mathematics (NCTM) Focal Areas for prekindergarten (2006) and Clements' (2004a) developmental trajectories for grades Pre-K-2, to articulate our learning objectives for mathematics. The mathematics domains covered include: number sense, operations, geometry, and measurement. The "big ideas" – the most important concepts and skills – are addressed within each domain. Drawing upon the substantial research conducted in this area, we place a priority within *MTP-Math* on development of children's number sense (over one-half of *MTP-Math* activities address knowledge and skills in this domain), defined as involving written numeral recognition, oral counting (including organizing numbers in sequence), and object counting (extended to between-group comparisons of magnitude and subitizing) (Jordan, Kaplan, Nabors Ola'h, & Locuniak, 2006; Siegler, 1991). Early number sense is a prerequisite to learning place value, number composition and decomposition, basic arithmetic operations, and understanding of mathematical properties (Baroody, 2009; Griffin, 2004; Jordan, 2007; Miura, Okamoto, Kim, Steere, & Fayol, 1993; NCTM, 2008; NMAP, 2008; Van de Walle, 2003). Within *MTP-Math*, we reinforce early place value conceptions using a number chart displaying color-coded numerals and corresponding ten-frames (blue for the *tens* place, orange for the *ones* place) to illustrate each number from 0 to 39. In addition, number sense has been found to be an important predictor of academic success in early elementary grades (Jordan, Kaplan, Locuniak, & Ramineni, 2007; Stock et al., 2009) as well as in high school (Duncan et al., 2007; Ginsburg & Allardice, 1984).

Building on this strong foundation of number sense, students learn to perform simple mathematical operations, including equal partitioning and combining/separating of groups of objects. Recognition and creation of shapes and solids, as well as repeating patterns is the focus of geometry. Within measurement, students explore length, weight, and area/volume.

MTP-Science

The Benchmarks for Science Literacy from the American Association for the Advancement of Science (AAAS) (1993) and National Science Education Standards (NRC, 2006) articulate trajectories for grades K-2 and K-4, respectively; we used a review of state prekindergarten standards to refine our learning objectives for pre-k. The *MTP-Science* curriculum addresses three domains of science: life science, earth science, and physical science with

inquiry-based activities to meet instructional objectives that are aligned with state and national standards. The activities guide students in construction of conceptual understandings across these broad domains, including (Life Science) Humans, Animals, and Plants; (Earth Science) Weather, Day/Night, and Earth Materials; and (Physical Science) Properties of Materials, Movement, and Physical Change. As shown in Table 1, our distribution of activities across these domains is in general alignment with that reflected in an assessment of national standards for pre-kindergarten science reported by Greenfield (2010). Activities were designed to provide opportunities to apply inquiry skills to predict, observe, analyze, and describe their findings, and to use simple science tools including a hand lens and balance. (For additional information on the MTP-M/S curricular design and its evolution, please see Kinzie, Vick Whittaker, McGuire, Lee, & Kilday, 2014.)

MTP teacher support system

As we previously describe, high fidelity curricular implementation can be a struggle for early childhood teachers (Pianta et al., 2005), and a particular problem where mathematics and science are concerned. This is due in part to limited professional development for teachers (NRC, 2006) and lack of teacher experience and confidence (Copley, 2004; Stipeck, 2008). Teachers' practice clearly matters for students' learning; In the Tennessee state-wide Project STAR, between 12% and 14% of student performance in the primary grades was accounted for by between-teacher variation in effectiveness, with effects much more pronounced for mathematics achievement as compared to reading, and for lower-SES schools (Nye, Konstantopoulos, & Hedges, 2004). This relationship between lower-performing teachers and low-SES schools was underlined by results obtained by LoCasale-Crouch et al. (2007) in an eleven-state study of 692 pre-k classrooms: Teachers serving the highest proportion of children at-risk for early school failure were also those teachers performing at the lowest quality levels. Given the persistence of differences observed for children from low SES households (NCES, 2009, 2011), it seems especially important that their teachers receive the best possible support to implement high quality curricula effectively.

Design of MTP-M/S teacher supports

In acknowledging the inadequate preparation of the preschool teaching force, the National Research Council (2005) advises that curricula be comprehensive enough to enable success for teachers without strong preparation or experience. In response and to help encourage transfer to teachers' practice, we articulated a range of teaching supports that would be quick and easy for teachers to use as they prepared to facilitate a learning activity. While some of these supports are "within-activity" supports provided to all MTP-M/S teachers (see Table 1 for a description), most are provided via the hybrid MTP-M/S Plus package tested here, including a combination of on-line implementation supports, enhanced with a one-day summer workshop day and seven, 2.5 h teacher workshops (a total of 23.5 h outside the classroom). This hybrid format was intended to provide teachers with easy access to supports in multiple media, largely on the teachers' own schedule, and minimizing the amount of professional development time required to effectively support teachers (compare to the average of 49 h of professional development found to be effective by Yoon, Duncan, Lee, Scarloss, & Shapley, 2007 in their review of effective programs).

As with our curricular designs, a theoretical basis for design of the MTP-M/S teacher supports is informed by the tenets of situated cognition, by anchoring the supports to teachers' authentic tasks and encouraging their reflection on everyday practice (Brown et al., 1989; CTGV, 1990); we embed teacher supports in the physical and social contexts of teachers' practice (Putnam & Borko,

2000). The MTP-M/S professional development supports were also intended to promote high fidelity (including adherence and quality) implementation of the MTP-M/S curricula. Given that large-scale observational studies show clear linkages between the quality of teacher-student interactions and student learning outcomes (NCEDL and SWEEP, see Early et al., 2005), we specifically focused on the characteristics of high-quality teacher-student interactions using a well-validated framework for encouraging classroom quality, the *Classroom Assessment Scoring System* (CLASS; Pianta, La Paro, & Hamre, 2008). We also aimed to enhance teachers' mathematics and science concept knowledge and understandings of how to foster mathematics and science learning in early education, as recommended by the National Research Council (2006, 2009). The pedagogical and content focus for our teacher supports is summarized in Table 1, as well as the formats used, which are described next.

MTP-M/S plus teacher support formats

Drawing upon actual pre-kindergarten teachers' implementations of the curricula, we provided over 130, 2–3 min demonstration videos that illustrated high-quality teacher-child interactions and highly inherent implementations of the curricula – one or more demonstration videos for every activity. Targeted video demonstrations have been found to be more effective than textual descriptions in developing teachers' pedagogical knowledge (Moreno & Ortegado-Layne, 2008). Video-based quality teaching challenges were also provided once each week, featuring one of the activities for the week and posing a reflective question on professional practice, to be answered while watching a short video clip of another teachers' implementation. A mathematics or science educational expert offers feedback on that practice. As we have described elsewhere (Kinzie, Vick Whittaker, Kilday, & Williford, 2012), video-based observation and reflection can encourage authentic experiential learning (Kolb, 1984) and reflection on action (Schön, 1987) without the pressures of being in “the teaching moment” (Borko, Jacobs, Eiteljorg, & Pittman, 2008).

Videos were also used to illustrate a different dimension of quality teaching (CLASS video and dimension of the month), including a 1–2-min video, demonstrating excellent teaching practice on the current month's dimension of quality (e.g., *quality of feedback*), a brief description of the dimension and why it's important, and links to more information on all ten dimensions of quality teaching, as well as a quality teaching library offering 150 video examples across many instructional settings, formats, and content areas.

Brief teaching tips (we aimed for 25 words or fewer) were provided to highlight best pedagogical practices, common ways students construct understandings (including misconceptions to be on the alert for), or explanations of key mathematics or science concepts to aid teachers in their instruction. The *Plus* workshops were largely designed to help encourage teachers' use of the on-line support system. To help encourage their use of the on-line supports and provide opportunities for teacher reflection and peer discussion on their teaching practice, teachers in the MTP-M/S *Plus* group also participated in a one-day summer workshop and seven half-day (2.5 instructional hours each) workshops, spaced across the year. Each workshop focused on a specific dimension of quality teaching as defined in the *Classroom Assessment Scoring System* (CLASS Pre-K; Pianta et al., 2008), most in the context of mathematics activities ($n = 2$ workshops) or science activities ($n = 4$ workshops), along with explorations of concept knowledge, self- and peer-reviews of teaching, error analysis activities (modeling common student behaviors as teachers practice identifying errors and guiding learning, based in part of recommendations from the National Research Council (2006).

In sum, while there is emerging research lending support for a number of mathematics and science curricula (Clements & Sarama,

2008; French, 2004; Starkey et al., 2004), these curricular packages are not yet in widespread use, and there are few products that offer both mathematics as well as science curricula. The goal of the present study was to fill this gap in the research by examining the effects of empirically based mathematics and science curricula and accompanying hybrid teacher support system on children's mathematics and science knowledge and skills.

Present study

We conducted a small experimental study in pre-k classrooms during the 2009–2010 school-year to evaluate the potential of MTP-M/S to increase preschool children's mathematics and science knowledge and skills across the pre-k year. Specifically, the purpose of the present study was to compare the development of mathematics and science skills for children whose teachers were assigned to one of three conditions: MTP-M/S curricula plus teacher support system (*Plus*), MTP-M/S curricula only (*Basic*), or *Business as Usual* (*BaU*). We hypothesized that students whose teachers participated in the MTP-M/S *Plus* and *Basic* conditions would show greater mathematics and science achievement in the spring compared with students whose teachers participated in the *BaU* condition. Because of the research suggesting the need for both high-quality curricula and support for their implementation, we hypothesized that students whose teachers participated in the MTP-M/S *Plus* condition would return the best performance on assessments of mathematics and science skills, compared to students whose teachers participated in the *Basic* and *BaU* conditions.

Method

Participants

The sample for the current study included 42 pre-kindergarten teachers and 444 of their students, from full-day state-funded classrooms in a single school district of a large mid-Atlantic city (11 *Business as Usual* teachers, 17 MTP-M/S *Basic* teachers, and 14 MTP-M/S *Plus* teachers). All teachers in this study taught in Title 1 schools which serve high percentages of children from low-income families. The teachers were mostly female (98%) and ranged in age from 24 years to 65 years ($M = 45$, Median = 48, $SD = 10.72$). Teachers reported their race/ethnicity as Caucasian (54%), African American (44%), or Other Race (2%). Teachers held an average of 18.5 years of experience working professionally with infants to elementary-aged children (Median = 16.5, $SD = 10.05$) and all held at least a Bachelor's degree (54% had a degree in early childhood education) as was a requirement for teachers in state-funded classrooms (see Table 2 for descriptive information on teachers and classrooms).

A total of 444 students participated in the study (an average of 10 randomly selected students per classroom). Participating students were all kindergarten-eligible for the subsequent academic year, and average 4.76 years old ($SD = .31$). Parents of students (49% male) reported their race/ethnicity as African American (66%), Caucasian (26%) or other race (8%). The sample was predominantly low income; the average income-to-needs ratio (computed by taking the family income, exclusive of federal aid, and dividing this by the federal poverty threshold for that family) was 1.34 ($SD = .98$) with 40% of households having ratios lower than one (below the poverty line) and 78% of families having ratios lower than two. There was a range in mothers' highest level of education from eighth grade or less to a Master's degree (high school diploma or less, 35%; some college but no degree, 28%; two-year degree or training certificate, 28%; BA or above, 9%). Students' demographic characteristics are presented in Table 2.

Table 2

Child, family and teacher characteristics, by condition.

Child/family characteristics	Control (<i>business as usual</i>) n = 116			Curricula only (<i>basic</i>) n = 182			Curricula plus supports (<i>plus</i>) n = 146		
	(%)	n	Missing	(%)	n	Missing	(%)	n	Missing
Gender		114	2		181	1		140	6
Boy	57%			48%			45%		
Girl	43%			52%			55%		
Race/ethnicity		115	1		182	0		140	6
African American	60%			71%			64%		
Caucasian	31%			21%			28%		
Other	8%			8%			8%		
Maternal education		101	15		175	7		139	7
Less than high school	27%			41%			33%		
Some college but no degree	34%			26%			25%		
Two-year degree or training certificate	29%			25%			31%		
Bachelor's or above	10%			8%			11%		
Teacher characteristics	Control (<i>Business as usual</i>) n = 11			Curricula only (<i>basic</i>) n = 17			Curricula plus supports (<i>plus</i>) n = 14		
	(%) M(SD)	n	Missing	(%) M(SD)	n	Missing	(%) M(SD)	n	Missing
Teacher education		9	2		14	3		13	1
Bachelor's	54%			21%			22%		
Bachelor's plus one	15%			7%			33%		
Master's	31%			72%			45%		
Teacher yrs experience	14.41 (10.18)			18.00 (9.87)			22.50 (9.31)		

There was attrition of both teachers/classrooms and students over the course of the study. We conducted several analyses to examine potential attrition bias at both levels. Over the course of the study, seven teachers/classrooms dropped out: The school district pulled four teachers (two *Basic* teachers, two *Plus*) to participate in another study, while three teachers dropped for other reasons (personal circumstance [$n = 1$ *Plus* teacher], and work load [$n = 2$ *Business as Usual* teachers]), for an attrition rate of 17%. To estimate attrition bias, we conducted analyses comparing teacher and classroom characteristics for the 35 teachers who fully participated and the seven teachers who dropped from the study. There were no significant differences (all p 's > .05) between the teachers who fully participated and those who dropped from the study on the covariates (mother's education, family income, child gender, child race, teacher education, teacher years of experience) or the values of the pre-test measures assessed at baseline (TEMA-3, GMA, LiS, EPS).

Initially, 416 students were selected to participate and completed fall assessments. Of these, 69 students could not be assessed in the spring due to teacher withdrawal from the study or student withdrawal from the preschool. To offset child attrition in classrooms where teachers were still participating, an additional 28 students were selected from the original pool of consented students for the spring assessment. All students with some child data were included in the study (see description of analyses, below). There were no significant differences when comparing children who had both fall and spring data ($n = 317$) to children who had only fall or only spring data ($n = 127$) with regard to age, gender, ethnicity, maternal education or family income.

Intervention and previous findings

In this study, we tested the effects of the *MyTeachingPartner-Math/Science* (MTP-M/S) curricula and teacher support system on children's math and science skills. We have reported elsewhere (Kinzie et al., 2012) on the fidelity with which teachers implemented the curricula, with this sample. As part of their participation in this study, we asked teachers to videotape themselves implementing MTP-M/S curricular activities. Tapes were coded for adherence to the curricular design. Overall, teachers in both *Basic* and *Plus* intervention groups showed fairly high adherence to the

curricula as assessed by the MTP-M/S Fidelity Measure (Kinzie et al., 2012). Across activities, out of a possible total of 24 points, *Basic* teachers scored an average of 13.67 ($SD = 3.98$) and *Plus* teachers scored an average of 15.19 ($SD = 1.97$). In examining the distribution on each fidelity item, we found that the majority of teachers got scores of "yes" on the dichotomous items and scores of "most" or "all" on the ordinal items. There were no significant differences in *Basic* and *Plus* teachers' adherence to the curricula, however, in examining the standard deviations for each group, it appeared that there was more variability in teachers' scores in the *Basic* group than in the *Plus* group.

Finally, for teachers in the *Plus* group, we examined descriptive statistics regarding their use of implementation supports (Kinzie et al., 2012). Almost all of the teachers in the *Plus* group attended the initial summer workshop (with one day spent on the curricula) and the seven, 2.5-h professional development workshops ($M = 6.18$ workshops/teacher, $SD = 1.17$). Teachers' use of web-based resources was tracked using a server that automatically recorded the information about teachers' access of the online supports. There was a very large range in teachers' website usage, with teachers ranging from 1.18 to 21.05 h ($M = 10.52$, $SD = 6.80$) spent on the website.

Materials

Business as usual (BaU) group

The district followed the *HighScope* curriculum (HighScope Educational Research Foundation, 2012) as a base, with a district-prepared pre-kindergarten curricular guide addressing a range of topics in oral language, literacy, mathematics, science, history, and social science. The district's mathematics and science activities were explicitly informed by state pre-kindergarten learning standards and by the *High Scope* curriculum, as well as by assessments of early learning (including the *High Scope Child Observation Record* [COR] and quarterly assessments in each subject area). Relevant to mathematics and science, the instructional strands addressed include: number and number sense; computation; measurement; geometry; data collection and statistics; patterns and relationships; scientific investigation, reasoning, and logic; matter (physical motion and forms of water); earth and space systems;

earth patterns, cycles, and change; resources; and history/change over time.

Basic and plus treatment groups

The *Basic* group received the *MTP-M/S* curricula described above and the teaching materials needed to implement the activities. The *Plus* group received the *MTP-M/S* curricula, needed materials and also access to the teacher support system of on-line professional development supports and related workshops. Both intervention groups were encouraged to fully implement the *MTP-M/S* curricula as well as any other mathematics and science activities they would like.

Procedures

Recruitment and random assignment

Teachers were recruited from a single district in a large mid-Atlantic city. Invitation letters that described the mathematics and science curricula and the professional development supports were sent to all pre-kindergarten teachers in the district. Several informational meetings were held with interested teachers to describe the study in more detail. Follow-up phone calls and/or in person meetings were held with interested teachers.

Teachers who consented to participate attended an introductory workshop in the fall, during which they were oriented to the purpose of the study, trained on the intervention to which they were assigned, and given information about data collection requirements. Teachers in all three groups completed a survey describing their own and their classroom's characteristics, in the fall and in the spring.

The experimental evaluation was carried out using stratified random assignment with schools being randomly assigned to one of the three conditions. We stratified schools ($n = 24$) by number of participating teachers. Random assignment was conducted at the school level to try to prevent contamination of intervention effects across conditions.

At the beginning of the school year, participating teachers sent home a consent form and short family demographic survey to all parents or guardians of their students, with a request that these be completed and returned. Ninety-four percent of parents consented to allow their children to participate in the study (529 out of 578 parents). Based on the parental consent received, we randomly selected ten students per classroom for participation in fall and spring direct assessments. Students were excluded from the study if they were reported by their teachers to have an Individualized Education Plan for a severe developmental delay or learning disorder (6% of students) or limited English proficiency (3% of students) because we did not have valid and reliable measures of students' math and science knowledge and skills for these populations.

Training for data collection

Data collectors completed two full days of didactic training on administration of the direct child assessments (prior to fall assessments and prior to assessments in the spring). Data collectors were assessed using an extensive checklist during live practice to ensure that each data collector's test administration and scoring skills were reliable and that they adhered to the standardized administration manuals. Additionally, data collectors conducted four practice assessments on their own, and sent their data to the research team to be checked for completeness and accuracy, prior to assessment administration in the field.

Child assessment protocol

Data collectors were blind to the experimental condition of the students. At each assessment time point, students were brought to a quiet, private area and administered an assessment battery

lasting a total of approximately 1 h (two sessions of 30 min each, with a 30 min break in between). After completion of the assessments, students were given a book for their participation. After all participating students had been assessed, all other students in these classrooms were given a book.

The fall assessments were conducted approximately six weeks after the start of the school year, to enable teachers to establish classroom routines and provide a period of acclimatization for students who were new to the school experience. The ordering of children to participate in the fall assessment was random. Approximately 26 weeks ($M = 26.47$, $SD = .79$) after completion of the fall assessments, the spring assessments were undertaken, with students assessed in the same order as in the fall, helping to ensure that approximately the same amount of time had elapsed for all students assessed.

Measures

Teacher and classroom characteristics

On the fall survey, teachers reported about their professional experience (e.g., education level, field of study, years of experience) and their classroom composition (e.g., number of students, gender, ethnicity, and language).

Child and family characteristics

Parents or caregivers completed a survey that provided information about their child's date of birth, gender, race/ethnicity, and Individualized Educational Plan (IEP) status, as well as maternal education, family income, and what languages were spoken in the home.

Number sense and operations

Students' knowledge of numbers and numerical operations were tested using the *Test of Early Mathematic Ability – 3rd Edition* (TEMA-3; Ginsburg & Baroody, 2003). This standardized measure uses pictures and counting chips to assess students' skills in number knowledge, such as cardinality, ordinality, one-to-one correspondence and enumeration, and their abilities in numerical operations. The TEMA-3 has parallel forms (A and B) and is designed to be given to children between the ages of 3 and 8 years, as either a diagnostic tool for children having difficulty in a specific mathematics domain or to determine how a child is performing in relation to his or her peers. The measure is norm-referenced, and has been found to be a reliable and valid test of early mathematical ability (Bliss, 2006; Ginsburg & Baroody, 2003). Concurrent validity has been reported by TEMA developers, with both the *KeyMath R Basic Concepts* subtest ($r = .54$) and the *Young Children's Achievement Test Math Quotient* ($r = .91$). In our administrations, this measure showed excellent internal reliability in both the fall ($\alpha = .91$) and spring ($\alpha = .93$).

Geometry and measurement

The *Geometry and Measurement Assessment* (GMA) is a derivative of the *Tools for Early Assessment of Mathematics* (TEAM; Sarama, Clements, & Wolfe, 2011), and is specifically designed to assess children's knowledge of shapes, patterns, measurement and positional words. For our study, six TEAM items were retained intact, seven questions were developed as extensions on questions in the TEAM (for example, with the TEAM, children are asked to make a triangle and a rectangle using coffee stirrers and we added a related question for making a square), and seventeen new items were developed to address additional related curricular objectives not assessed in the TEAM (for example, after a TEAM item asking children to identify the longer of two sets of linking cubes, children are given a third set of linking cubes and asked to order the three sets from shortest to longest). Construct validity has been established for the TEAM

(Clements, Sarama, & Liu, 2008). In our administration, internal reliability for this measure was .82 in the fall and .86 in the spring.

Number sense and place value

In order to examine the effects of the *MTP-Math* activities focusing on foundational place value conceptions, and given the lack of existing measures focusing on this knowledge/skill for our pre-k population, project staff found it necessary to develop The *Number Sense and Place Value Assessment* (NPV). Dynamic assessments provide an indication of the level of support needed for performance (Pena, Iglesias, & Lidz, 2001), in contrast to conventional assessments that generally indicate only a static indication of performance on any given item (Justice & Ezell, 1999), and so provide more information about children's level of understanding.

The NPV contains two parts: *Number Sense* items evaluate students' rational counting skills and numeral recognition skills, while *Place Value* items measure students' concrete understanding of place value, as reflected by students' ability to match numerals to corresponding 10-frame representations, specifically testing students' emerging understanding of the ones place and tens place. Overall, the assessment includes nine items, with dynamic assessment implemented on seven of the nine items via scaffolding: When a child cannot respond to an item correctly, a series of scaffolds (successive verbal prompts, some with use of 10-frame or number line manipulatives, with the final scaffold being joint performance with the adult) are provided, with each correspondingly reducing the possible score. Students can score a total of 41 points on the measure if no scaffolds are required to answer these items correctly.

Prior to its use in the current study, the NPV was pilot-tested with 44 randomly selected students between the ages of 54 and 66 months, drawn from a convenience sample of six pre-k classrooms intended to serve a low-income population in the mid-Atlantic. We observed that provision of scaffolds in this assessment improved children's performance on both parts of the assessment, effectively identifying children's level of successful performance before the final scaffolds available were required. Children's performance on the two NPV components, number sense and place value, was significantly correlated ($r = .511$; $p < .002$; Kinzie et al., 2014).

With this administration we determined internal consistency for the NPV measure to be good, at .89. Concurrent validity was also determined with this administration: NPV performance was significantly correlated with children's performance on the mathematics achievement measures (TEMA, $\beta = 0.74$, GMA, $\beta = 0.61$, $p < .01$).

Life sciences and earth and physical sciences

As no science assessments were currently available for pre-k administration, the *MyTeachingPartner-Math/Science* research team created two assessments to enable examination of science learning outcomes. The *Life Science Assessment* (LiS) and *Earth and Physical Science Assessment* (EPS) were created following a review of national and state standards for science learning in pre-kindergarten. A core set of objectives were identified through a process of cross-referencing between sets of standards. These objectives were used to create assessment items, in forced-choice and card-sort forms, as the National Science Education Standards (NRC, 2006) suggest that concept knowledge be assessed in multiple different ways. For forced-choice items, students are asked to point to the appropriate picture or material. For example, a student is shown a picture of a tree and is asked the question, "What is this?" before being asked the forced-choice question, "Are trees plants or animals?" For card sorting items, students are asked to sort photographs according to a specific (forced-choice) dimension (e.g., plants versus animals, items that will float if placed in water versus those that will not).

The LiS assessment tests children's understanding of the biological world. These topics include living versus non-living things,

characteristics of plants and animals, human and animal bodies, using the senses, and plant and animal life cycles. The assessment contains 73 forced-choice and card-sort items, each worth 1 point. The measure had good internal reliability in the fall ($\alpha = .83$) and adequate internal reliability in the spring ($\alpha = .77$).

The EPS assessment determines students' understandings of scientific tools, weather, temperature, material composition, motion, and buoyancy. The assessment contains 19 forced-choice and card-sort items with a total possible score of 39. The measure had adequate internal reliability in the fall and spring ($\alpha = .74$ and $.77$, respectively).

Multi-level analyses

The structure of the data included three potential levels at which the data could be analyzed: child, classroom, and school. Because randomization occurred at the school level, it could be argued that this is where the clustering should occur. However, the number of schools included ($N = 24$) is too small to trust multilevel models that are performed using this variable as a cluster variable (Maas & Hox, 2005). We performed interclass correlations for both schools and teachers for all of our models and found that the ICCs were very similar. Therefore, we chose to fit two-level HLM models that accounted for the nesting of students within classrooms. The resulting data structure involved an average of 10 children in each of the 42 teacher's classes. Data were analyzed using *Mplus version 6.1* (Muthen & Muthen, 1997–2010). Missing data for any one variable ranged between 6% and 20%. Analyses were run using full information maximum likelihood estimation so that data analyses used all available data from each case (444 students across 42 classrooms) when estimating parameters and therefore increasing the statistical power of estimated parameters (Enders & Bandalos, 2001). Demographic variables that have typically been included as control variables in the developmental literature were included: children's ethnicity, child gender, and maternal education (Moilanen, Shaw, Dishion, Gardner, & Wilson, 2010; Smith, Calkins, Keane, Anastopoulos, & Shelton, 2004; Wanless, McClelland, Tominey, & Acock, 2011).

We fit a series of models examining differences in children's mathematics and science skills for children in the *Business as Usual*, *Basic*, and *Plus* groups, controlling for fall mathematics and science skills and child characteristics. The level-1 model specifies that children's spring mathematics or science skills are a function of their fall pretest score, gender (girl = 1, boy = 0), ethnicity, and maternal education (continuous variable ranging from eighth grade or less to a doctorate degree). Three dummy variables were created for ethnicity and entered simultaneously so that Caucasian ethnicity served as the reference group and the different indicators corresponded to African Americans, Hispanics, and those of other ethnicities.

In the level-2 model, teachers' study condition was entered. Two dummy variables were created and entered simultaneously so that Business-as-Usual teachers were the reference group and the different indicators corresponded to those in the Basic group and those in the Plus group. The level-2 model also included the classroom-level aggregate of the pretest score, the teacher's education level, and the teacher's total amount of teaching experience as covariates. We calculated effect sizes for the significant treatment effects using Hedge's g , dividing the difference between adjusted means for the two groups by the standard deviation for the outcome in the control group.

Results

Table 3 provides descriptive statistics for outcome variables included in our models. We conducted Wald Z omnibus tests to

Table 3
Pre and post-test scores for outcome measures, by condition.

Outcome measures	Control (<i>business as usual</i>) N = 116			Curricula only (<i>basic</i>) N = 182			Curricula plus supports (<i>plus</i>) N = 146		
	Mean (SD)	n	Missing	Mean (SD)	n	Missing	Mean (SD)	n	Missing
TEMA-3									
Pre	11.94 (6.73)	109	7	9.50 (6.55)	168	14	10.87 (5.91)	138	8
Post	19.38 (9.14)	87	59	16.2 (8.87)	145	37	18.41 (8.28)	107	39
GMA									
Pre	13.35 (4.96)	109	7	11.11 (4.71)	168	14	12.25 (4.34)	138	8
Post	16.49 (4.93)	87	59	15.15 (5.62)	145	37	17.91 (4.28)	107	39
NPV									
Pre	–			–			–		
Post	29.93 (6.16)	87	59	28.79 (7.16)	145	37	31.48 (5.76)	107	39
LiS									
Pre	38.68 (5.76)	108	8	38.89 (5.24)	168	14	38.48 (5.56)	138	8
Post	43.28 (4.35)	87	59	42.72 (4.58)	145	37	44.22 (4.56)	107	39
EPS									
Pre	37.24 (5.94)	107	9	35.16 (6.18)	168	14	35.71 (5.97)	138	8
Post	40.42 (6.29)	86	60	39.34 (6.39)	144	38	40.59 (5.83)	107	39

examine whether there were baseline differences across groups (*MTP-Plus*, *MTP-Basic*, *BaU*) with regards to teacher (i.e., highest level of education, years of experience) and classroom characteristics (i.e., average maternal education), and children's pre-test scores. We observed a significant group differences in teachers' level of education (Wald $Z=6.46$, $p=.04$), such that those in the *Basic* group had the greatest education, followed by those in the *Plus* group, followed by those in the *BaU* group. We found no significant differences across groups on any of the other teacher or classroom characteristics. There were significant differences in children's mean scores on pre-test assessments of children's number sense and operations skills (Wald $Z=8.29$, $p=.02$), where those in the *BaU* group had the highest pre-test means ($M=11.94$, $SD=6.73$), followed by those in the *Plus* group ($M=10.87$, $SD=5.91$), followed by those in the *Basic* group ($M=9.50$, $SD=6.55$). There were also significant differences in pre-test assessments of children's geometry and measurement skills (Wald $Z=10.28$, $p=.006$), where those in the *BaU* group had the highest scores ($M=13.35$, $SD=4.96$), followed by those in the *Plus* group ($M=12.25$, $SD=4.34$), followed by those in the *Basic* group ($M=11.11$, $SD=4.71$). Baseline differences in the other child outcomes were not significant.

Are there differences, based on treatment condition, in children's mathematics gains across the pre-k year?

Unconditional models suggested that between 3% and 19% of the variance in children's mathematics scores was between classrooms (ICCs=.03–.19), with the remainder attributable to child characteristics. Coefficients for the covariates included in our models are provided in Table 4. The estimated marginal means for the different treatment groups (controlling for the covariates) are presented in Table 5. Comparisons for the homogenous subsets comparing the *BaU* group to the *Basic* and *Plus* groups are based on the tests of the dummy codes from the multilevel model discussed above. The comparison of the *Basic* to the *Plus* group is taken from a dummy code in a second model that was identical to the model discussed above except that the *Basic* group was the reference group for the treatment dummy codes.

There was a significant omnibus effect of treatment on children's geometry and measurement skills (Wald $Z=6.32$, $p=.04$). Specifically, controlling for students' fall scores and demographic characteristics, those in the *Plus* group had significantly greater gains on the *GMA* than students in the *BaU* group (effect size $g=.52$). Students in the *Basic* group did not differ from those in the *Plus* or *BaU* groups.

There was also a significant omnibus effect of treatment on children's number sense and place value skills (Wald $Z=6.88$, $p=.03$). Students in the *Plus* group scored significantly higher on the *NPV* measure compared to students in the *Basic* ($g=.35$) and *Business as Usual* conditions ($g=.47$). Students in the *Basic* group did not differ from those in the *BaU* group.

There was not an overall effect of treatment on children's gains in number sense and operations as measured by the *TEMA-3* (Wald $Z=.07$, $p=.97$).

Are there differences, based on treatment condition, in children's science knowledge and skills at the end of the year?

Unconditional models suggested 4–7% of the variance in children's science scores was attributable to classrooms (ICCs=.04–.07). There was no overall effect of treatment on children's gains in life science (Wald $Z=3.77$, $p=.15$) or earth and physical science (Wald $Z=1.30$, $p=.52$).

Discussion

This study examined the potential of *MyTeachingPartner-Math/Science* for improving preschool children's mathematics and science knowledge and skills. We hypothesized that students whose teachers participated in the *MTP-M/S Plus* and *Basic* conditions would show greater mathematics and science achievement in the spring compared with students whose teachers participated in the *BaU* condition. Further, we hypothesized that there would be greater achievement for students of teachers in the *Plus* group compared with the *Basic* group. These hypotheses for positive treatment effects for the *Plus* group over the *Basic* and *BaU* groups were partially supported for the mathematics domain, but not for science.

In comparison with the *BaU* group, students of *Plus* group teachers demonstrated (with medium effect size) greater learning in geometry and measurement. Geometry and measurement are two areas that are fundamental concepts in cognitive development, but which typically receive less attention in pre-k classrooms (Clements & Sarama, 2011). In our study, compared with *Business-as-Usual* classrooms, *MTP-M/S* classrooms had a greater emphasis on geometry and measurement (15.2% of *MTP-Math* curricular activities focused on geometry [compared to 12.6% in the *BaU* classrooms] and 19.7% of *MTP-Math* activities emphasized measurement skills [compared to 15.2% of activities in the *BaU* classrooms]). The learning trajectories in these areas are complex and require careful scaffolding by teachers to advance children's skills, however, early childhood teachers have had few professional development

Table 4

Effects of MTP-M/S intervention on children's development of math and science skills during pre-k.

	TEMA-3 (number sense/ operations) β (SE)	GMA (geometry/ measurement) β (SE)	NPV (number sense/ place value) β (SE)	LiS (life sciences) β (SE)	EPS (earth/physical sciences) β (SE)
<i>Level-1 Covariates</i>					
Pre-test	0.740*** (0.034)	0.496*** (0.050)	–	0.606*** (0.039)	0.499*** (0.044)
Gender (girl)	–0.036 (0.028)	0.062 (0.051)	0.028 (0.052)	0.026 (0.048)	–0.026 (0.048)
African American	–0.011 (0.041)	–0.166*** (0.042)	–0.105 (0.065)	–0.065 (0.049)	–0.172*** (0.042)
Hispanic	0.025 (0.045)	0.090 (0.051)	–0.015 (0.037)	0.068 (0.05)	–0.008 (0.058)
Other	0.06 (0.039)	–0.029 (0.036)	0.053 (0.056)	–0.032 (0.047)	–0.063 (0.054)
Maternal education	0.03 (0.039)	0.094* (0.043)	0.175** (0.066)	0.01 (0.05)	0.048 (0.049)
<i>Level-2 covariates</i>					
Pre-test	0.854 (1.833)	0.928*** (0.244)	–	0.791 (0.509)	0.548 (0.464)
Teacher education	0.032 (0.997)	0.004 (0.206)	0.426 (0.236)	–0.078 (0.481)	0.468 (0.574)
Teacher experience	0.106 (0.399)	–0.149 (0.190)	–0.008 (0.233)	–0.006 (0.267)	–0.202 (0.353)
<i>Treatment effects</i>					
(Basic–control) dummy	0.148 (1.839)	0.392 (0.332)	–0.173 (0.266)	–0.341 (0.27)	–0.063 (0.354)
(Plus–control) dummy	–0.014 (0.537)	0.601* (0.258)	0.485* (0.222)	0.314 (0.342)	0.379 (0.408)
(Plus–basic) dummy ^a	–.163 (1.347)	0.234 (0.232)	0.678** (0.225)	0.669* (0.273)	0.457 (0.450)

^a The effect of the (basic–plus) dummy code was taken from a second model using Basic as the reference group for the treatment dummy codes.* $p < .05$.** $p < .01$.*** $p < .001$.

experiences related to teaching geometry and measurement (National Research Council, 2009). The teacher supports for those in the *MTP-M/S Plus* group offered opportunities for teachers to view effective implementation of activities in these areas by viewing the demo videos, perhaps increasing the quality of their implementation of these activities (as compared to those in the *MTP-Basic* group).

Students of teachers in the *Plus* group outperformed students in both the *Basic* and *BaU* conditions in number sense and place value skills (with small to medium effect sizes). This *Plus* group advantage may have been the result of these teachers' participation in two monthly workshops focusing on best pedagogical practices related to number sense and place value, as well as access to substantial related online supports provided for all curricular domains (including Demonstration videos and Teaching Tips underlining pedagogy, ways children construct meaning, and key mathematics and science concepts). The online supports in the number sense and place value domains may have been particularly useful as *MTP-Math* activities included learning objectives that were developmentally more challenging than traditional pre-kindergarten lessons that cover basic number sense concepts such as oral counting and number recognition. For example, *MTP-Math* activities cover topics such as subitizing, stable order-principle, cardinality, composing and decomposing numbers, and unitizing into groups of five and ten.

With regard to children's gains in the *TEMA-3* assessment of knowledge and skills in numbers and operations, the marginal means in the treatment groups were greater than the marginal mean for the *BaU* group but the differences were not significant.

The lack of between-group differences on this measure may have been due to the similarly strong weighting of number sense activities in the *MTP-Math* curriculum (57% addressed knowledge and skills in this domain) as well in *BaU* classrooms, where we observed 47.4% of mathematics activities implemented emphasizing number sense. It may also be that the *TEMA-3* did not discriminate well at the point of the fall pretesting; as noted by Bliss (2006), this measure does not have an appropriately deep floor for children until they are aged 4 years, 3 months.

The results we obtained for geometry and measurement outcomes as well as for number sense and place value suggest that the combination of the *MTP-M/S* curricula and teacher support system offer some benefit for teachers serving children from low-income families. In these areas, it appears that the provision of professional development supports were necessary to produce significant gains in children's scores. Professional development is thought to be key to educational reform (Sarama, DiBiase, Clements, & Spitler, 2004), with increases in teacher professional development and in-service education linked to improvements in classroom quality and children's development (Bowman et al., 2001). This may be especially true in math domains such as geometry and measurement and number sense and place value. In these domains, teachers not only need to describe and demonstrate correct use of numbers but may also be called on more directly to apply mathematical knowledge for teaching. Pedagogical knowledge for mathematics includes the ability to use pictures or diagrams to represent mathematic concepts to students, as well as analyze students' conceptual development (Hill, Rowan, & Ball, 2005); both are called

Table 5

Estimated spring marginal means and homogenous subsets by condition.

	Business as usual (control)	Curricula only (basic)	Curricula plus supports (plus)	Overall test for treatment (Wald Z)
TEMA-3 (number sense and operations)	17.66665 _a	17.81465 _a	17.65265 _a	Z = .07 p = .97
GMA (geometry and measurement)	11.7188 _a	12.1108 _{ab}	12.3198 _{bc}	Z = 6.32 p = .04
NPV (number sense and place value)	29.74892 _a	29.68492 _a	30.38592 _b	Z = 6.88 p = .03
LIS (life science)	43.37576 _{ab}	43.03476 _a	43.68976 _{bc}	Z = 3.77 p = .15
EPS (earth and physical sciences)	39.91307 _a	39.85007 _a	40.29207 _a	Z = 1.30 p = .52

Note. Means within a row that do not share any subscripts are significantly different ($p < .05$). Means for *TEMA-3*, *GMA*, *LIS*, and *EPS* control for Fall scores and all covariates. Means for *NPV* only control for covariates because there was no Fall assessment of *NPV*.

upon to effectively scaffold students' geometry and measurement and number sense skills.

Other studies examining effects of mathematics curricula on students math skills have found a range in effect sizes from small (0.08; [Sophian, 2004](#)) to large (1.07; [Clements & Sarama, 2008](#)). Our moderate effect sizes for geometry and measurement (0.52) and number sense and place value (0.47) fall in the middle. Those interventions that found large effect sizes ([Clements & Sarama, 2007b, 2008](#)) tended to include a coach for teachers, and also extensive hours of professional development. For example, *MTP-M/S* teachers in the *Plus* group received 23.5 h of professional development across both mathematics and science curricula, compared to 50 h of professional development (including 16 h of personalized classroom observation and coaching twice each month) offered in support of the single *Building Blocks* mathematics curriculum ([Clements & Sarama, 2008](#)).

There is an emerging group of studies suggesting that the positive effects associated with interventions may be more likely seen in teachers' second year of implementation, relative to their first. [Clements, Sarama, Spitler, Lange, and Wolfe \(2011a\)](#) purposively delayed direct assessment of student learning until the second year of teachers' implementation of *Building Blocks*, with positive results for this curriculum ($ES=0.72$). In the *Preschool Curriculum Evaluation Research (PCER, 2008)* evaluation of *Pre-K Mathematics* (supplemented by *DLM Early Childhood Express Math Software*), 80% of teachers were in their second year of curricular implementation; beneficial results were found on an abbreviated form of the *Child Math Assessment*, ($ES=0.44$) and on the *Building Blocks Test of Shape Composition* ($ES=0.96$). In an evaluation of *Big Math for Little Kids (BMLK)*, an effect size of 0.43 was identified in favor of this intervention, but only when students had entered kindergarten (during which time they continued to participate in *BMLK* curricular activities) ([Ginsburg, Lewis, & Clements, 2008](#)). These findings suggest the importance of an ongoing program of curricular implementation to ensure teacher familiarity, and also continued engagement in learning experiences across the early childhood years. It could be that we would see stronger effects on children's math outcomes, were teachers to implement *MTP-M/S* for a second year.

We did not find any significant differences in the omnibus tests across groups in children's gains in life science or earth and physical science. We note that, for *LiS*, students of teachers in the *Plus* group had significantly greater gains compared to those in the *Basic* group. For *EPS*, the marginal means for the *Plus* condition were greater compared to the *BaU* condition, although these differences were not significant. There have been only a few published results of science curricular trials for comparison. In these trials, researchers have found significant improvements in children's skills in areas other than science. Results from implementation of the *Early Childhood Hands-On Science (ECHOS)* curriculum suggest its benefit; with outcomes determined through teacher ratings using the *Galileo* measure. Results suggested that children in treatment classrooms, compared with control, made greater gains in Approaches to Learning, Early Math, Language and Literacy, and Creative Arts. However, there were not significant differences in children's science skills ([Greenfield, Jirout, et al., 2009](#)). (In small trials of the *ScienceStart!* Curriculum, the child outcomes have been assessed with a measure of receptive vocabulary, rather than science knowledge and/or skills, with improvements of 0.5 standard deviation; [French, 2004](#)). These studies show that science interventions can have positive effects on children's skills in domains other than science. In this study, we did not assess children's skills in areas other than science and math. A lack of well-validated and sensitive measures in the area of science is also suggested by this research. Our project-developed science measures were developed by the research team over a relatively short time period; it may be that

these measures need additional refinement in order to discriminate well. As noted by [Brenneman \(2011\)](#), "science is not among the domains that are well represented in the catalog of reliable and valid assessments available to educators and researchers" (p. 2.)

In this intervention, we were aiming to improve children's skills in two domains, as compared with many curriculum-focused interventions that focus on a single domain ([Clements & Sarama, 2007b, 2008](#); [Clements, Sarama, Spitler, et al., 2011](#); [French, 2004](#); [Ginsburg, Lewis, et al., 2008](#); [Greenfield, Jirout, et al., 2009](#)). This decision was purposeful, as math and science are two areas that are critically important to children's later learning ([Claessens & Engel, 2013](#); [Duncan et al., 2007](#); [Grissmer et al., 2010](#); [NMAP, 2008](#)), and are not well represented in teacher's instruction ([Early et al., 2010](#)). However, asking teachers to learn new curricula in not just one, but two subject areas, had implications for their cognitive load as well as the dosage of activities that children received and the amount of professional development afforded in each domain. By way of comparison in the area of dosage, students in *Building Blocks* classrooms experience about twice the amount of whole- and small-group classroom mathematics activities that *MTP-Math/Science* includes. In addition, *Building Blocks* students spend 10 minutes/week on related computer activities. These factors may be helpful in interpreting our effect sizes relative to those obtained in the other curricular trials described above. As researchers move toward development and implementation of cross-curricular packages addressing student learning and development in multiple domains, these moderate effect sizes may become the norm.

Limitations

There are several limitations that deserve attention. First, we conducted our analyses at the classroom level although random assignment was at the school level. One of the negative consequences that resulted from randomizing at the school level with a limited number of schools was that we saw some pre-test differences in children's skills. Children in classrooms assigned to *BaU* displayed significantly higher mathematics skills (number sense and operations and geometry and measurement) in the fall. Although we controlled for children's pre-test scores in related analyses, these differences suggest that *BaU* classrooms started the year with higher levels of math achievement than those in intervention classrooms. There is research to suggest that here may be a differential rate of growth in academic skills for students who those who start the year with higher versus lower skills, with children who start the year with higher skills growing at a higher rate compared with their peers ([Downey, von Hippel, & Broh, 2004](#)). It is possible that children in the *BaU* classrooms not only started the year with higher levels of math skills, but that these skills also grew at a faster rate than those in the *Basic* and *Plus* classrooms.

Second, unanticipated attrition at the classroom level (seven teachers/classrooms, 17% of sample, due to a district-level administrative decision), with 71% of attrited classrooms having been assigned to a treatment condition, negatively impacted our power to detect significant differences between treatment groups. A priori power analyses accounted for attrition at the child but not classroom level. Although we accounted for missing data in our analyses, this attrition resulted in lower power to detect significant results. And, because this attrition was not distributed across treatment condition it lowers our ability to make causal inferences.

Third, the effect sizes for our intervention were smaller compared to some other curriculum and PD packages focusing on early math or early science skills ([Clements & Sarama, 2008](#); [Clements, Sarama, Spitler, et al., 2011](#); [French, 2004](#)). This is likely due to the

lower intensity of MTP-M/S, due in part to the fact that our curriculum activities and PD sessions were split across two content areas.

Finally, given that several of the measures employed here were recently developed (*Number Sense and Place Value [NPV]*, *Life Science [LiS]*, and *Earth and Physical Science [EPS]*), care must be taken with the corresponding results obtained here. As described previously, these instruments were developed by the MTP research team in the absence of available measures for these domains of knowledge and skill, and working from the same learning objectives that guided curricular development. This is not an unusual practice in research in early childhood settings where few assessments exist in mathematics and science; Clements, Sarama and colleagues have expended substantial effort to develop their assessment of early mathematics learning (Clements & Sarama, 2007b, 2008; Clements, Sarama, Spitler, et al., 2011; Clements, Sarama, & Wolfe, 2011) as have Starkey, Klein, & Wakeley (2004), while Greenfield has been similarly engaged in development of direct assessments of science knowledge and skills (Greenfield, Dominguez, et al., 2009) while undertaking evaluative research on the ECHOS science curriculum. We note that the NPV was administered at post-test only. It is possible that different results would be obtained when variance associated with a pre-test is controlled for. Further study of these measures across early childhood settings, including situations in which our curricula are not in use, and in conjunction with other measurement will help us better understand the characteristics of these measures.

Conclusion and directions for future research

The findings reported here suggest that MTP-M/S curricula and teacher supports have value for encouraging mathematics learning for young children potentially at-risk for early school failure, adding to the emerging research in this area (Clements & Sarama, 2008; French, 2004; Starkey et al., 2004). We found in other analyses (Kinzie et al., 2012) that in the study described here, MTP-M/S was implemented with a high degree of adherence in both *Basic* and *Plus* classrooms, suggesting that the curricular instructions are accessible to teachers. Further, we found that the MTP-M/S *Plus* teachers had strong attendance at the professional development workshops and used the online teacher supports provided, which led to significantly less variability in teachers' adherence when compared with *Basic* teachers.

In our current research, we are evaluating the effects of the MTP-M/S curricula and teacher supports over multiple years, enabling teachers to surmount any "learning curves" involved in learning to implement these new curricula. In other studies, assessment of effects was deferred until teachers' second year of implementation, to good effect (Clements, Sarama, Spitler, et al., 2011; PCER, 2008). We are also collecting data on children's skills in domains other than mathematics and science, as some interventions that include math and/or science curricula have found impacts on language (French, 2004; Greenfield, Jirout, et al., 2009; Sarama, Lange, Clements, & Wolfe, 2012) and executive function (Weiland & Yoshikawa, 2013).

We are beginning to develop a better understanding of how to effectively support teachers' instructional interactions, to assist them in building a solid foundation for young children's mathematics and science learning. It is our hope that through research such as this, we can identify mechanisms (e.g., high-quality curricula and teacher professional development) through which we can help develop children's knowledge and skills in both mathematics and science. Ultimately, we hope that through these efforts, we will identify how to best support teachers in implementing high-quality mathematics and science curricula, and positively impact children's learning outcomes in these domains.

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